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Energy Use, Environmental Quality and Urban Population Change

Paper

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I I R - DISCUSSION 20 1984

1.0 INTRODUCTION

The topic of this paper is the relation between changes in environmental quality in an urban region and changes in the density of land use. Land value studies have shown (see e.g. Anderson and Crocker, 1971) that pollution does have an impact on land prices, which in turn depend on the value urban land users attribute to land at a given location. If land users utility is affected by environmental quality, then this fact implies that they will react to changes in the quality of living at their present location. These reactions can be of a political nature, attempting to improve environmental quality, a strategy which is quite costly in terms of transaction costs. They can also search for a new location, which offers them a bundle of characteristics preferable to the ones of their residence. This consideration leads us to the hypothesis, that migration flows should be influenced by environmental quality. The relation between these two variables could very well change intensity in the course of urban development. Particularly in the suburbanisation and desurbanisation stage this hypothesis should hold.

On the other hand emissions of residuals leading to pollution in an urban region depend on the density of land use and the rates of land use activities (such as energy consumption), as the total volume emitted in a given zone, depends on the number of land users settled there.

The present contribution is a further step in the direction of verifying the theoretical claim stated above (Schubert, 1979; 1980; 1982).

An empirical investigation has been hampered by the lack of appropriate data on a compatible spatial scale. Recently, however, environmental quality data have begun to sprout and empirical analysis is becoming feasible. Unfortunately this isn"t quite true yet, for the "political strategy", i.e. all forms of environmental policy. For this reason no attempt is made in the framework work of this contribution to analyse the impacts of environmental policy directly. The results presented here are an extension of some earlier work (Maier, Schubert and Brunner, 1981) and represent further results in a ongoing effort.

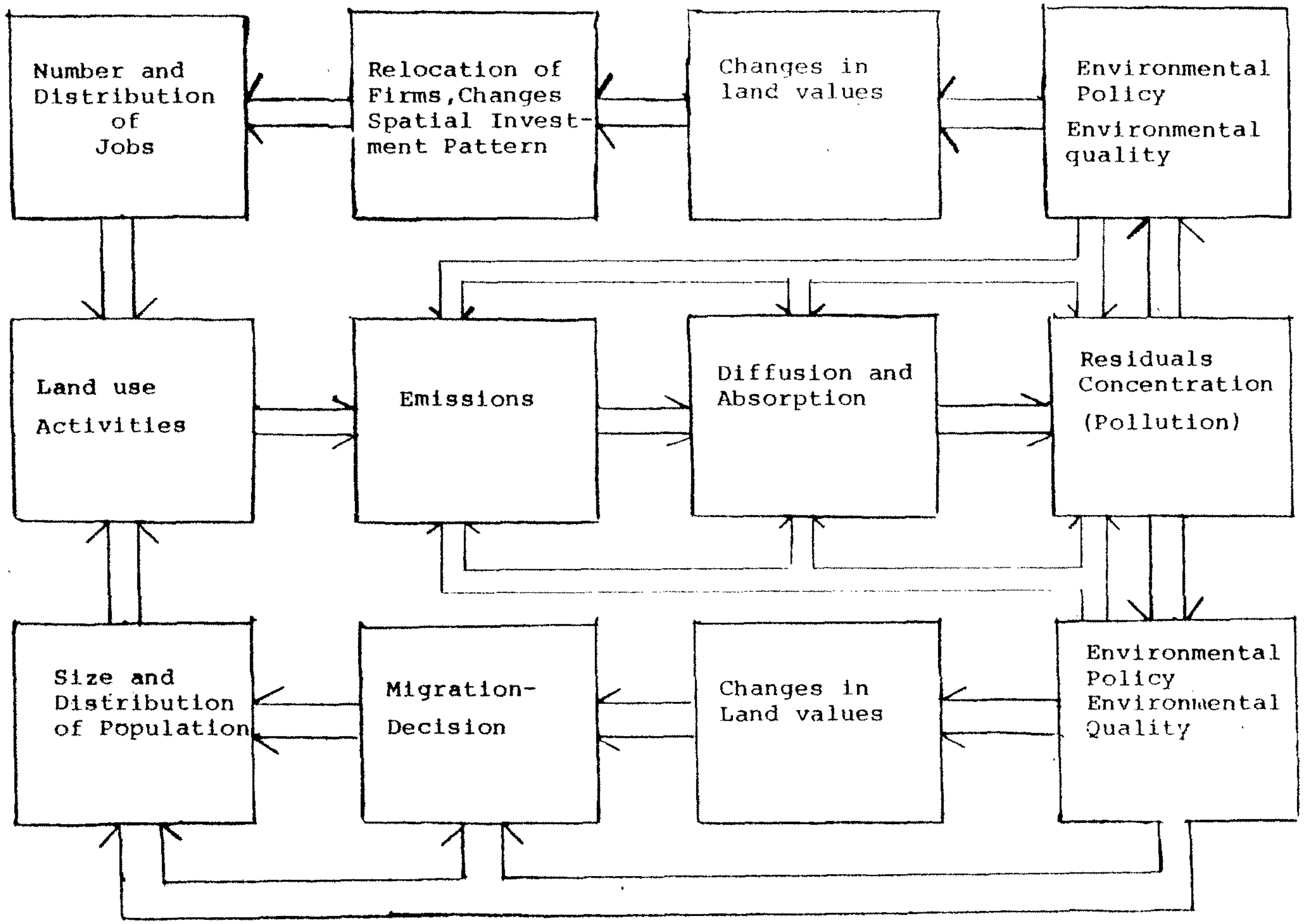
2.0 THE CONCEPTUAL FRAMEWORK

It is the main claim of this contribution that a dynamic, simultaneous feedback structure exists between the population distribution of an urban region and the distribution of pollutants over the urban area (see Schubert 1979; 1982).

In the population submodel it is assumed that the residents of the relevant region react to changes in environmental quality as they perceive it. These reactions can lead to relocation decisions which in turn influence the spatial distribution of population (see Schubert 1979; 1982; Polinsky and Shavell, 1976; Portney, Kneese and Sonstelie, 1974).

In the pollution submodel it is hypothesized that emissions depend on the distribution of land users over the urban area, implying that changes in environmental quality can, ceteris paribus, be traced back to changes in the population distribution. Figure 1 illustrates the claimed feedback structure schematically.

Figure 1. Population and environmental quality



Source: Schubert, 1983

The conceptual framework

In its most general form we could describe this simultaneous model by a set of simultaneous equations (see Schubert, 1979; 1982),

(1) $\bar{R} = R\ (\bar{P}, \ldots)$

(2) $\bar{P} = P\ (\bar{R}, \ldots)$

where $\bar{R}$ and $\bar{P}$ represent the spatial distribution of residuals (R) and population (P) over the urban area. Population is to be understood as residential as well as working population.

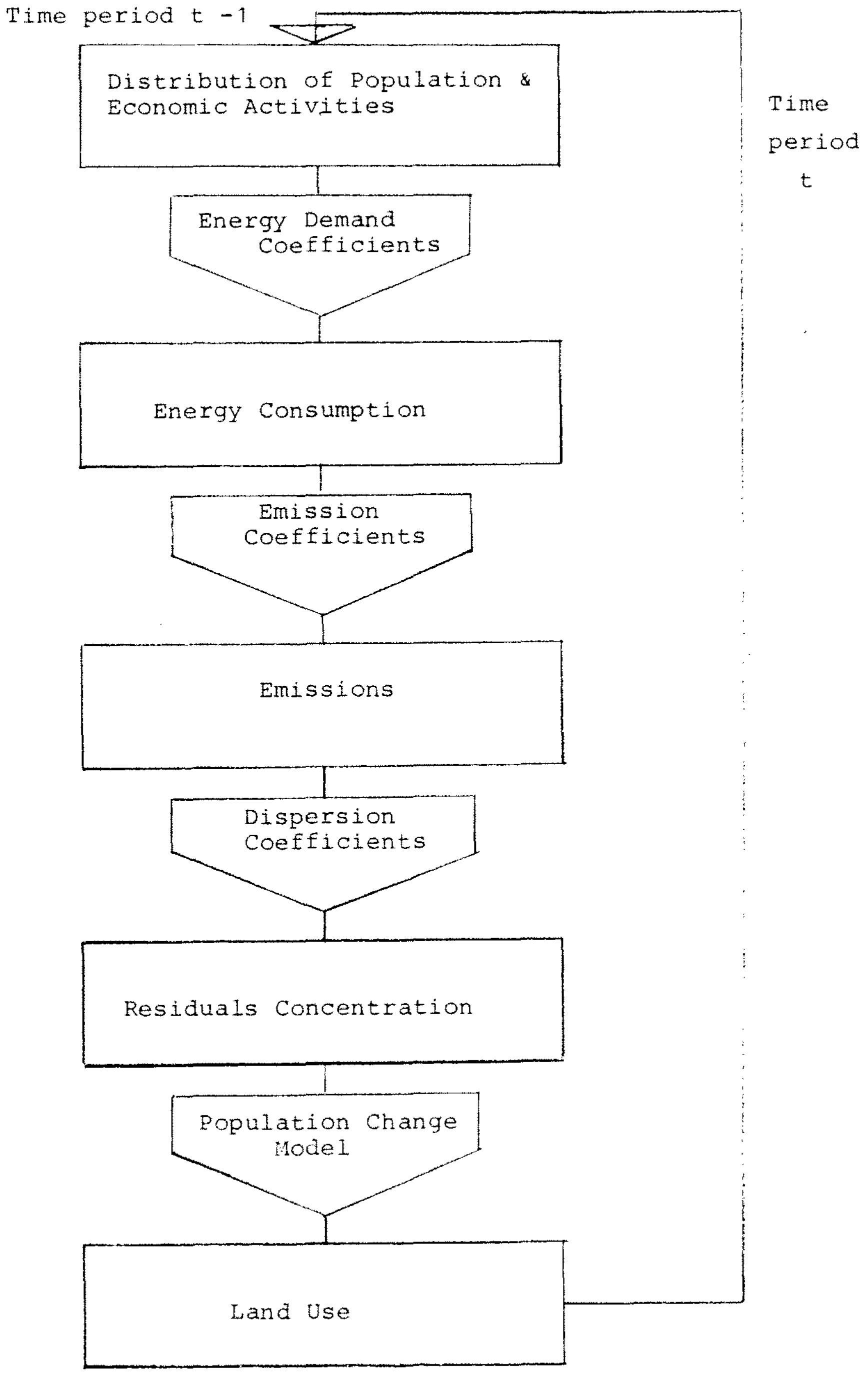
This process can be seen dynamically, i.e. as a set of simultaneous stock-flow relations. (These relations are described in more detail below). The interesting theoretical question is, what are the driving forces behind these flows? For the environmentally relevant variables, the physical law of the conservation of mass constitutes a critical factor, while in the population distribution problem the behavior of urban land users has to be analysed in more detail.

In the environmental submodel emissions of pollutants are seen as a by-product of land use activities. One of the most relevant of these activities in terms of emission intensity is the use of various fuels to produce energy, both as intermediate goods (such as electricity, etc.) and as a final output (room heating, etc.) or input for industrial purposes. Among the by-products of these transformation processes one can find many pollutants (such as fumes, aerosols, dust, noise, etc.) that have a substantial impact on the quality of living in urban areas. Many of these residuals are not only nuisances to urban residents but also hazards to their lives. In modern cities the problems of air-pollution and noise seem to be the most directly relevant factors for location decisions (see eg. JESTZ 1978).

It seems to be essential, therefore, to analyse the spatial distribution of energy use before attempting to work out the pattern of emissions over an urban area. Figure 2 shows the steps from the population distribution to "ambient environmental quality" (in terms of air pollution and noise) in the analytical framework.

Data limitations prevented us from working out a whole palette of maps of pollutants, so we had to make a choice which ones to include into the analysis. The intricacies of econometric booby traps made this approch even desirable, as the various pollutants tend to be highly co-linear, by their very nature of dependence on the volume of fuels consumed. For reasons of data availability as well as its prominent rank among urban environmental nuisances, sulphur-dioxide emission was selected as the "representative" air pollutant.

Figure 2. Environment and urbanisation, the analytical framework



Among the sources of noise, traffic seems to be the most notorious one on the average. In our case study area, the city of Innsbruck in Tirol, Austria, traffic implies often the high density, high speed freeway traffic passing through the urban region, constituting the main connection between Germany and Italy. So it was noise created by automobile traffic we analysed in this contribution.

Turning to the land use decisions next, it has to be admitted that we rather neglected the land use changes caused by the relocation of firms in the study area. No information is available to assess to what extent land price changes and environmental policy measures, among other variables having nothing to do with this topic directly, affect land use decision by urban firms. We did take their spatial distribution into account, when we tried to estimate energy consumption and emissions in the study region, we did not analyse the feedback, however.

The empirical analysis is essentially dynamic in nature, but the dynamics cannot be tested by means of appropriate longitudinal data. We were mostly stuck with a cross-section of the relevant variables over the zones constituting the study region. The parameters of the population change submodel are to be seen as more or less representative of a given period, they are most likely subject to change over longer periods of time, especially over different stages of urban development (see Schubert, 1983; v. d. Berg et al., 1982). A test of this hypothesis has to be postponed until the data permit this venture.

The structure of the model briefly outlined above, will be elaborated in more detail in the following sections.

3.0 THE SPATIAL FRAMEWORK

In this contribution the term "urban" is not to be understood in the sense of an administratively defined area. The phenomena to be discussed warrant the delimitation of a region within which the majority of interactions relating to the migration and commuting issue take place. Obviously the spatial extension of such areas varies greatly, depending on many factors, the most important one in this analysis has to do with the stage of urban development (see v.d. Berg et al., 1982).

The concept to be used for this specific task is a "Functional Urban Region (FUR)". We follow v.d. Berg et. al. (1982, p. 55):

> The concept of Functional Urban Regions is in practice interpreted as referring to nodal regions, identifying urban centres, and delimiting zones dependent on the centres. For lack of data on the interaction between small areas, functional urban regions are in fact delimited solely by the size of journey-to-work flows. It is essentially a spatial-interaction approach, trip distribution being considered a fundamental determinant of urban spatial structure.

within a FUR all contiguous and surrounding municipalities having a commuting rate of over 15 per cent to the core were included, defining the ring of the agglomeration. (Sisser, 1971; Conditt, 1978). In the case of Innsbruck this ring practically coincides with the county "Innsbruck - Land" so that all the 65 communities located in the county were defined as ring zones. This regionalisation offered the additional advantage of the availability of data for economic variables which were of great help in some of the consistency checks we were able to make particularly on the variables.

A second ring was defined by using data for the 2 adjacent counties, one to the West ("Imst") and one to the East ("Schwaz") of the FUR. As the study area is surrounded by mountains in the South and North that inhibit intensive interactions, areas North or South of Innsbruck- Land were not included in the analysis. (See map (1) in the appendix). Among the interactions from the second ring with the FUR included into the study indirectly were migration and the diffusion of residuals.

4.0 ENERGY CONSUMPTION

The use of fuels for the production of energy constitutes the urban land use activity which is mostly responsible for pollution. These transformation processes account for the majority of all air pollutants as well as noise in urban areas.

The level of energy consumption in each urban zone has to be determined, hence, to be able to compute these emissions. Actual energy consumption is regarded as the equilibrium between supply and demand for fuels in this section. As the prices for most fuels are world market prices, they will be considered as given for the consumer. What quantities of fuel are demanded by the urban land users at those prices?

To keep things as simple as possible, we assume profit maximizing firms (accepting world market prices as given). Further we postulate that their production functions be of a constant returns to scale type, in which different fuels for energy production are inputs (among others) (see Jorgenson, 1977). Profit maximization implies that the value of the marginal product of an input has to be equal to its price.

(3) $P_f = P_o(\frac{Y}{F})\phi$

where P_f...price of a unit of fuel (f)

P_o...price of output of firm

Y ...quantity of output produced by the firm

F ...quantity of fuel used as an input

ϕ ...elastisity of substitution of F

An elementary transformation yields the demand for the fuel considered:

(4) $F = (\frac{Po}{Pf})\ \phi Y = eY$

Ex post the term (Po/Pf) ϕ constitutes a constant in a given time period at spatially uniform prices and production technologies. If P_o and P_f are equilibrium prices, supply of a fuel equals its demand, so we can compute the quantity of a fuel consumed by mulitplying the "activity level" of the firm (i.e. its value added) by an "energy input coefficient". (Hudson and Jorgenson, 1976) Over time this coefficient will of course vary with energy prices and technological progress, as can be seen even in the simple formulation above (an econometric approach to the changes of energy coefficients was attempted e.g. by Schmoranz 1983).

In our case study we had no information on energy consumption for all urban zones available. We attempted to estimate the levels of energy use in the case study zones by making use of (4).

Two problems arose in this connection, i.e. no information of the net production values as such were available, only employment data for 10 economic sectors for each urban zone for 1976 were given (OESTZ, 1976). The net production values were estimated via values for this variable for the same year for the whole of Tyrol (see table (1) in the appendix).

On this basis the value added per employee could be computed and thus the required zonal figures.

The estimation of the energy demand coefficients (a) in (4) unfortunately had to rely on even more averaged out information, the value added figures. National energy use data for 3 types of fuel (coal, oil, wood) were the only source of information (see table (2)).

Table 2. Energy consumption coefficients for 3 types of fuel and 19 economic sectors, 1976.

1	3.49328E-05	0	0
2	2.59807E-05	2.37064E-05	0
3	6.02157E-07	9.10498E-06	3.02592E-09
4	3.72223E-06	1.01888E-04	3.15443E-07
5	7.2968E-07	5.8442E-06	2.49983E-06
6	1.56315E-05	1.64359E-05	2.5782E-05
7	1.79784E-06	7.97099E-06	1.74547E-08
8	0	1.52423E-05	0
9	5.37768E-06	3.83326E-05	1.18516E-07
10	2.33448E-04	3.08901E-05	0
11	2.81733E-07	2.80942E-06	2.0576E-08
12	1.36037E-04	4.86029E-05	8.66729E-06
13	4.45379E-08	3.38488E-06	2.78362E-07
14	9.30862E-07	2.64974E-06	0
15	5.18692E-06	2.20364E-05	0
16	1.90829E-06	1.44911E-06	4.93735E-09
17	4.44213E-07	9.70958E-07	0
18	9.82341E-06	1.96525E-05	5.73128E-07
19	2.61826E-04	7.61614E-05	4.9248E-06

Source: Computations by the authors

Table (3) in the appendix presents the results, i.e. the estimated quantities of coal, oil and wood consumed in each of the 65 zones aggregated over all 19 sectors and the households (for which a similar approach was chosen). The 3 types of fuel mentioned were selected, as they are the most relevent for SO-2 emissions. It was assumed that only a desulphurized kind of oil was used, which is obligatory for households and is used also by most firms (there is no heavy industry in the study area).

Unfortunately no possibility exists at the moment to check the accuracy of these computations. It seems, however, that the estimates for households could be too low, the ones for the firms too high. This assessment can only be made indirectly, as there are official SO-2 emission figures for the whole of Tyrol by sector, which point in the direction mentioned above. (see also section 5)

Energy use by automobiles leading to noise pollution in the region presents a more difficult problem. No information is available to compute a meaningful proportionality factor between gasoline and diesel consumption and noise. We decided, hence, to use the average number of vehicles passing through a zone per day as a proxy for noise pollution directly.

For some roads in the region we had figures on the number of vehicles passing through at our disposal. To be able to estimate the automobile traffic for all zones in the study area, we proceeded in the following way:

It was hypothesized that the number of vehicles passing through a zone is determined by the following relation:

(5) $T^i = \bar{\alpha}^i + \alpha C^i + OT^i$

where T^i = number of vehicles passing through zone (i)

C^i = number of commuters

OT^i= number of vehicles passing through zone i for other purposes (shopping, school, etc.)

A matrix of commuters between all zones in the area was available. A shortest path alogrithm permitted the determination of the optimal route for commuters (using an automobile) and thus made it possible to assign them to different zones they had to pass through. This was done for all origins and destinations resulting in a distribution of all commuters to routes and zones. Simple aggregation permitted the calculation of the hypothetical number of commuters passing through a zone.

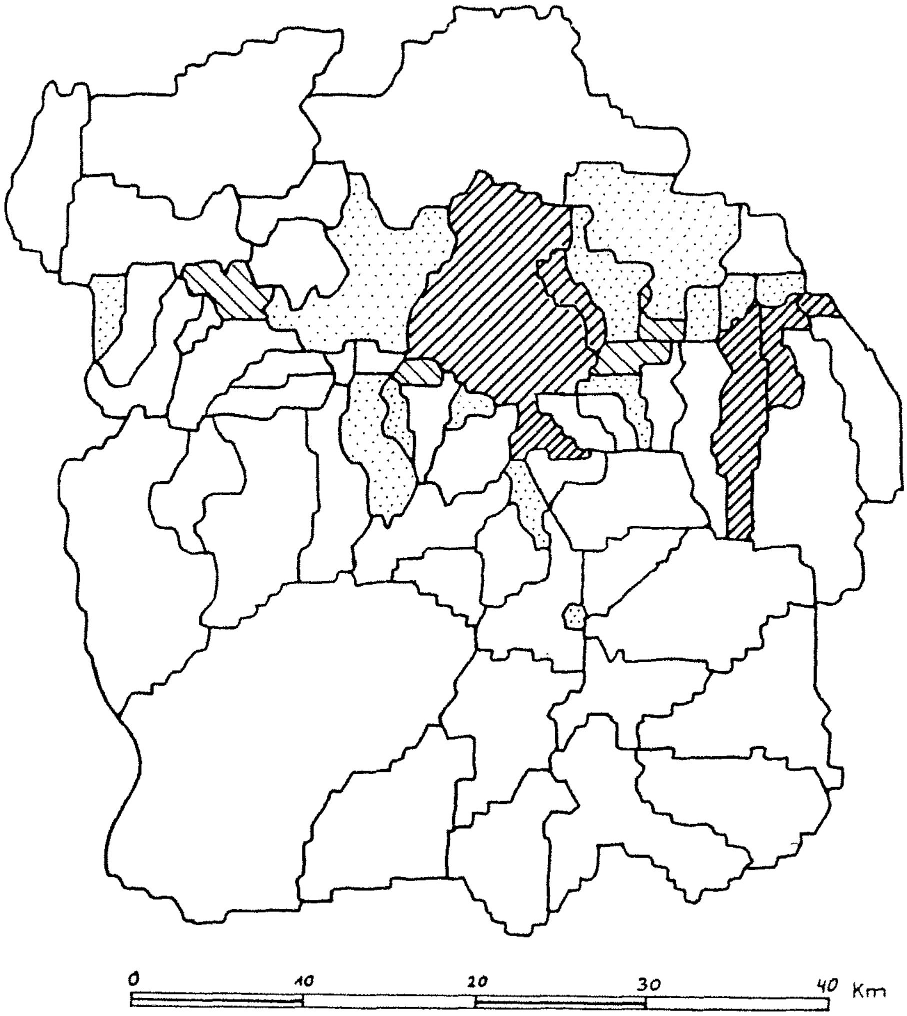
The "other trips" (OT) leading through a zone were hypothesized to depend on the size of and distance to the destinations that could be reached by passing through a zone. The size was represented by residential population. The distances were average travel times in a private automobile. These were estimated on the basis of a graph of the road system of the Innsbruck region, where the average speed was made dependent on the type of road (freeway, highway, local road) and the terrain (flat, mountains).

Population potentials were computed using the following formula:

$$(6)\quad \bar{P}^i = \Sigma^j P^j f(d^{ij})$$

These estimates were used as observations in a regression (see table (4) in the appendix), which permitted the computation of automobile traffic density on all roads in the study region, even where no direct information was obtainable. For each urban zone the number of roads of different types leading to the zone was found from a road map. The estimated number of vehicles on all of these routes through the zone were then aggregated and divided by the number of routes to yield the average estimated total volume of automobile traffic in all of the zones. The results can be inspected in map (2).

Map 2. "Noise" caused by automobile traffic
(traffic density in the Innsbruck FUR)



more than 10200

.... 8000 to 10200

.... 5200 to 8000

less than 5200

Source: Computations by the authors

5.0 THE ENVIRONMENT

In the framework of this paper we will deal with the natural environment, the quality of which is changed by the human land use activities (production and consumption of goods and services).

Two types of impacts of these economic activities on the natural environment can be distinguished. Production and consumption activities can lead to pollution, i.e. a deterioration of the quality of the natural environment.

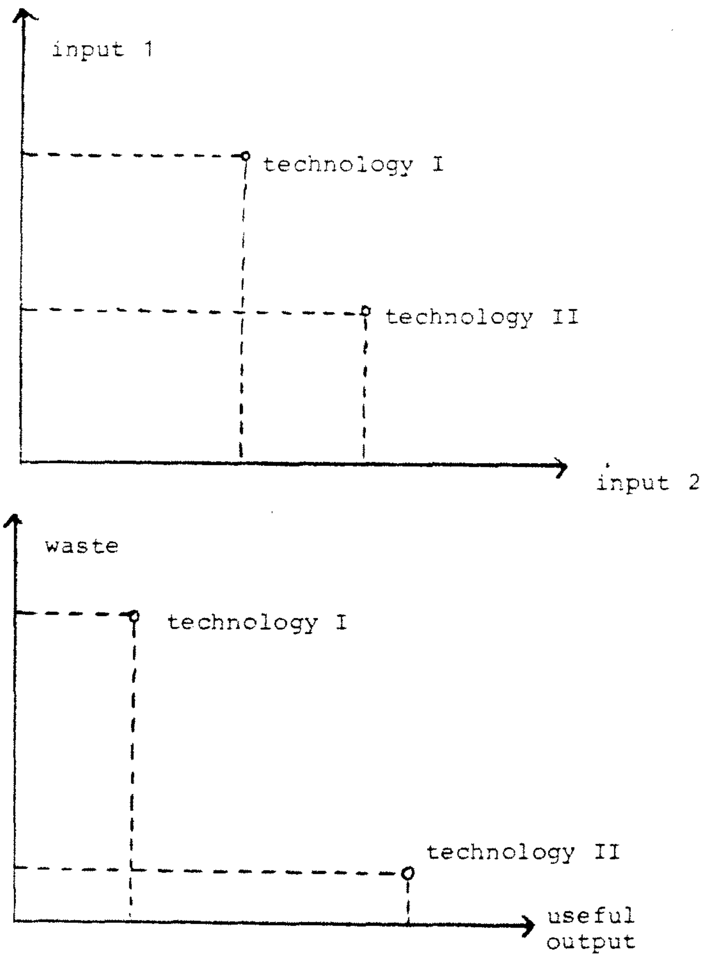
The emission-residuals concentration model briefly described in the sequel is implied, when "environmental quality" is mentioned. The stock variable (R) indicates the volume of pollutants in a given zone (i) which has a negative effect on the well-being of the residents in the area. The flow variable emissions (E) corresponds to the volume of pollutants emitted in the region i at the time t. These are due to the various land use activities in zone i. These activities can be of a stationary nature ("point sources") or the sources of emissions can be moving ("area sources"), such as automobiles.

The analysis has to start from a fundamental law of physics, the conservation of mass (see e.g. Ayres & Kneese, 1969).

It implies that the total mass of inputs into a production or consumption process has to be equal to the total mass of the outputs, which consists of "useful" goods and services and waste. The qualitative mixture of these inputs as well as outputs can vary greatly, depending on the technology applied. A technology is defined as a combination of inputs and outputs (see figure 3). (For more details the reader can consult any textbook on environmental economics, e.g. Kneese and Bowers, 1972; Nijkamp, 1976; Baumol and Oates, 1970; Bohm and Kneese, 1971; Dorfman and Dorfman, 1972; Frey, 1972; Mills, 1975; Victor, 1972; etc.).

If more than one technology exists for the production of useful products (or services for the consumer), the problem of technology choice arises. Standard economic theory postulates that this choice depends on the prices of inputs and outputs (or their expected values), as well as legal norms and regulations in the case of a productive enterprise and on prices, regulations, income and preferences for the consumer. The goal of doing the best with given income, price, etc. constraints often leads to the selection (and in the long run also development) of technologies that imply more waste than desirable and technologically necessary. This result often comes about by the non-inclusion of the "social cost" factors into the production and consumption decision (see e.g. Baumol and Oates, 1970). The core of environmental policy is to "internalize" these social cost variables into

Figure 3. Inputs, outputs, technologies.



the allocation decision of households and thus diminish the level of environmental externalities.

Once a technology has been chosen, the emission of pollutants can be determined.

The simplest way to calculate these emissions due to an activity, is hence, to use technological information to estimate "emission coefficients" relating activity levels and emissions of residuals. We thus arrive at a linear relation between emissions and activity levels for all land users.

(7) $E_t = \rho X$, where X is the activity level

(see e.g. Muller, 1977; Leontief and Ford, 1971; OECD, 1977; den Hartog et al., 1976; Luptacik et al., 1980; 1982).

Table (5) in the appendix shows the emission coefficients for sulphur dioxide for different kinds of fuel (OESTZ, 1978).

On the basis of these figures we estimated the emission coefficients for the 19 economic sectors for which data were available on the level of 65 zones in the Innsbruck FUR and 63 zones in the second ring. (For these sectors energy consumption was estimated for each zone, see section 4.0.). The following table (table (6)) presents an overview of the emission coefficients used to compute the SO-2 emissions emanating from each zone from stationary sources.

Table 6. Emission coefficients for SO_2 for 19 economic sectors and 3 types of fuel.

.0170	.0480	.0028
.0240	.0458	.0028
.0180	.0458	.0028
.0180	.0458	.0028
.0240	.0458	.0028
.0240	.0458	.0028
.0240	.0458	.0028
.0240	.0458	.0028
.0240	.0458	.0028
.0240	.0458	.0028
.0240	.0458	.0028
.0150	.0460	.0028
.0180	.0458	.0028
.0145	.0140	.0028
.0180	.0114	.0028
.0180	.0114	.0028
.0180	.0136	.0028
.0140	.0136	.0028
.0180	.0114	.0028

Source: Estimates by authors based on OeStZ (1978)

In the next step we computed the total SO-2 emissions in each zone by first calculating the emissions in each sector. This was achieved by multiplying the energy consumption in each sector in all zones by the appropriate emission coefficients and subsequent aggregation over all sectors and fuels for each zone.

An overview is presented in table (7) and map (3) in the appendix.

To find the dispersion coefficients ε_t^{ji} (in 8) we have to turn to physics and meteorology. These parameters are generally believed to decay with distance from the emission source. Furthermore the predominant direction of wind in the region has to be taken into account (see Muller and Lesuis, 1974; Dennis, 1977; Muller, 1977).

The pysical process can be paraphrased as: Emission - diffusion - absorption - residuals concentration. The total volume of pollutants emitted at a source is distributed to the surrounding areas ("diffusion"). (For a description of the process, see e.g. Isard, 1972; Muller, 1977; Dennis, 1977; Schubert, 1979; Benarie, 1980).

Based on a meteorological-physical model of residual dispersion, one can build up a matrix of spatial diffusion coefficients. They are the amount of residual concentration in i caused by one unit of emissions in j. Total residual concentration can simply be calculated summing up the contributions from all units in the region plus concentration caused by emissions outside the region. A part of the total volumes of emitted residuals arrives at the other locations.

Let the emissions arriving at location i be proportional to the volume of residuals emitted at j.

(8) $E_t^{ji} = \varepsilon_t^{ji} \, E_t^{j}$

The total volume of pollutants arriving in i is then equal to:

$$(9)\quad E^i_t = \sum^j \varepsilon^{ji}_t E^j_t + \bar{N}\bar{E}^i_t,$$

$$\text{where}\quad 0 \le \varepsilon^{ji}_t \le 1 \text{ and } \sum^j \varepsilon^{ij} = 1$$

$\bar{N}\bar{E}$ is the volume of pollutants from the "rest of the world". The stock of pollutants is then equal to the stock still left over from the preceding period plus the addition "diffusing" to region i from the other regions, minus the residuals "absorbed" by nature ($\gamma^i_t R^i_t$)

$$(10)\quad R^i_t = R^i_{t-1} + \sum^j \varepsilon^{ji}_t E^j_t + \bar{N}\bar{E}_t - \gamma^i_t R^i_t$$

In a long run diffusion process the stock of pollutants left over from the preceding period can be neglected.

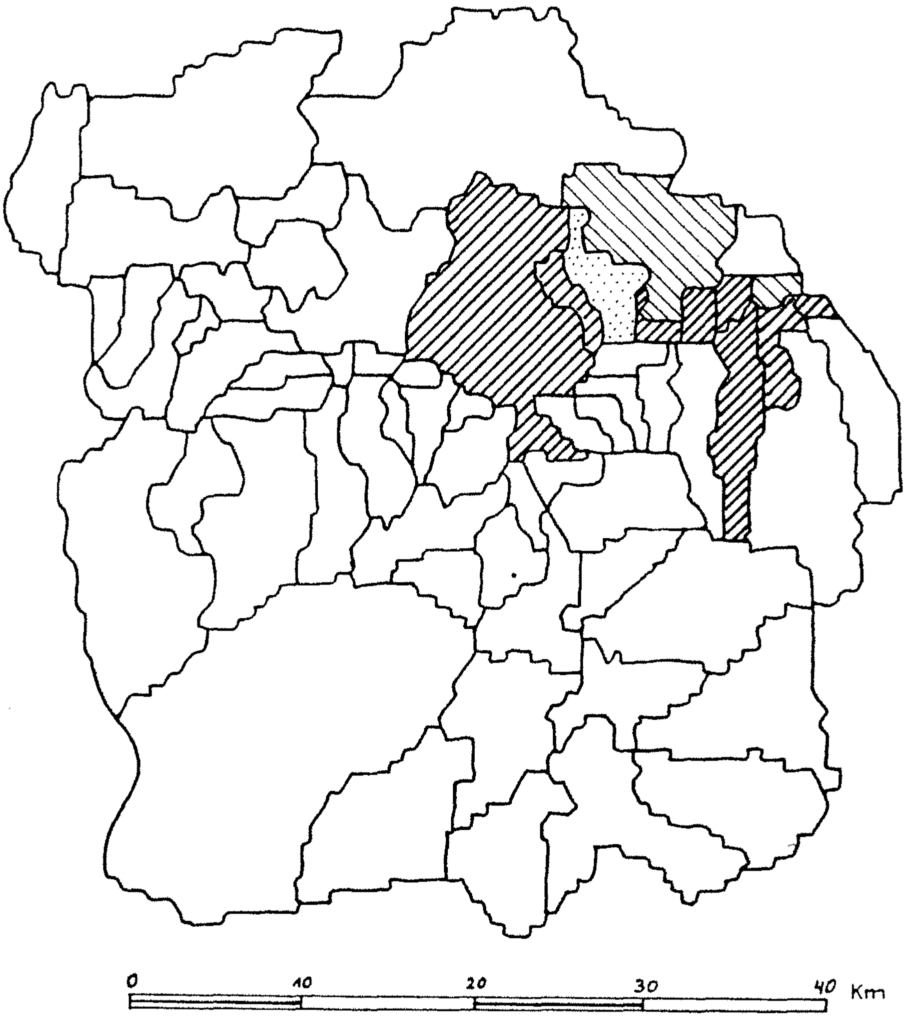
The computation of the matrix of spatial diffusion coefficients was based on a meteorological diffusion model for the Inn-valley, the mathematical details of which can be found in Vergeiner et. al. (1981). For our purpose we did not assume average meteorological conditions, but a problem situation, rather likely for the case study region during winter. (inversion layer 320 meters above ground and winds from the west with 1 meter per second speed.)

This selection is motivated by the opinion that there is increasing marginal disutility of pollution and therefore the peaks in residual concentration during winter tend to guide the migration decision.

An overview of the calculated steady state diffusion coefficients is presented in table (8) in the appendix. Table (9) presents the figures of the estimated levels of residuals concentration in the FU9 (see also map (4)).

Are these estimates empirically valid? Unfortunately no data are available which permit a rigorous statistical test. There is some evidence, however, that can be used for evaluation of the goodness of the estimates. The Tyrolean state government has published same aggregate figures for all Tyrolean counties and some maps indicating the spatial distribution of SO-2 emissions (among other pollutants) over the whole state, on a per square kilometer grid system. (Amt der Tiroler Landesregierung, 1981) As our emissions are computed for communities of varying size and on a much coarser spatial scale, no direct comparison was possible. It appears that in terms of absolute numbers our estimates of emissions for households are too low, while the industrial emissions are overestimated. Visual inspection of the published maps (see map (5) in the appendix) seems to indicate that the estimated spatial distribution is fairly accurate. As this distribution is the decision factor in the population change submodel, the absolute numbers do not matter too much in this study.

Map 4. Residuals concentration (SO_2) in the Innsbruck FUR



more than 3700

.... 2500 to 3700

.... 1300 to 2500

less than 1300

Source: Computations by the authors

The deterioration of the quality of living, due to noise, is an other variable to consider in a migration study. The most important source of noise is usually the traffic of vehicles. As no information was available to relate traffic density to measured noise levels, we decided to use this density as such as a proxy (see section 4.0. above).

Table 9. Residuals concentration (SO_2) in the Innsbruck FUR.

101	4569353.48	326	17911.37	348	48964.25
301	2800783.81	327	108074.12	349	35120.98
302	503915.61	328	105167.08	350	105683.15
303	598933.25	329	4370173.82	351	53389.86
304	234507.81	330	99711.24	352	15228.44
305	3774993.72	331	290413.48	353	176648.68
306	261558.89	332	382797.20	354	4920246.68
307	92806.49	333	67083.10	355	78081.44
308	737265.63	334	29382.69	356	55832.26
309	3668259.47	335	1021091.12	357	827203.63
310	76240.65	336	6561.36	358	2418364.13
311	178625.54	337	245631.22	359	12471.98
312	258361.23	338	123870.30	360	186089.55
313	54148.43	339	762053.74	361	720391.63
314	6973.11	340	992301.27	362	21386.71
315	122222.17	341	120745.19	364	688273.16
317	2987.07	342	724796.19	365	4365083.51
319	668061.34	343	199722.01	366	223672.64
320	693677.43	344	11975.42	367	4289776.82
322	4043675.80	345	187910.05	368	145042.61
323	227504.65	346	4181411.02	369	705477.74
325	245390.75	347	2752.95		

Source: Computations by the authors

6.0 POPULATION

There is a fundamental stock-flow-relationship in the population sector to consider too. The stock of population residing in zone (i) at time (t) is equal to the stock at the same location in the previous period (t-1) plus net natural population change (i.e. births minus deaths) and net migration (i.e. immigration minus emigration).

$$(11)\quad P_t^i = P_{t-1}^i + (B_t^i - D_t^i) + (I_t^i - O_t^i)$$

where P_t^i ... residential population in (i) at (t)
B_t^i ... births in (i) at (t)
D_t^i ... deaths in (i) at (t)
I_t^i ... Immigrants into (i) at (t)
O_t^i ... Emigrants out of (i) at (t)

Migration flows are usually represented in a migration matrix (M). It is useful to have the full matrix, including the main diagonal, indicating the number of non-migrants between (t-1) and (t) in zone (i).

$$(12)\quad M_t^{ii} = P_{t-1}^i - O_t^i$$

Migration is a spatial interaction variable for which the following relations hold by definition:

$$(13)\quad I_t^i = \sum^{j \neq i} M_t^{ji}$$

$$(14)\quad O_t^i = \sum^{j \neq i} M_t^{ij}$$

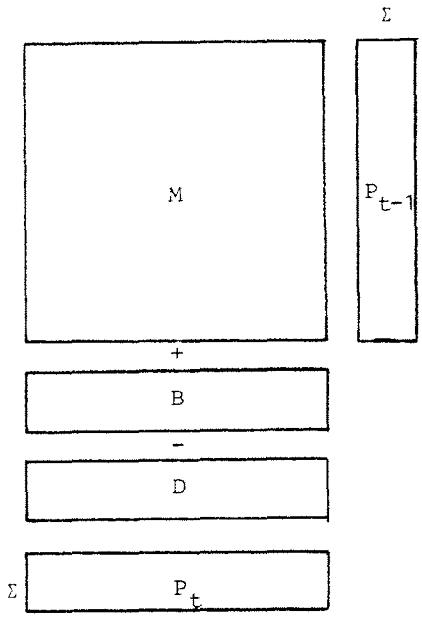
where M is the number of migrants from zone (i) to (j) and I and O are immigration and outmigration respectively.

It is easy to see from definitions (12) and (14) that the elements of matrix M sum up to the vector of population at (t-1) along the rows. The vector of population at (t) is gained by summing along the columns, adding the vector of births (B) and subtracting the vector of deaths (D). Figure (4) summarizes these relationships. For a more detailed discussion see Maier (1983).

In demographic modeling (see e.g. Rogers and Willekens, 1978; Keyfitz and Flieger, 1971; etc.) a very popular technique is to set up a "rates" model. Rates such as the propensity to migrate, to commute, the birth and death rates are defined and then often interpreted as transition probabilities in Markov models. Following this approach we can formulate the following relation:

$$(15)\quad M_t^{ij} = \mu_t^{ij} P_{t-1}^i, \qquad 0 \leq \mu_t^{ij} \leq 1$$

Figure 4. Relations between population components



Similarly birth rates β and death rates δ can be formulated such that (in the simplest version):

$$(16)\quad B_t^i = \beta_t^i \, P_t^i$$

$$(17)\quad D_t^i = \delta_t^i \, P_t^i$$

Note that, rather unconventionally, birth and death rates are defined on P_t, not P_{t-1}. This definition will be useful in the operationalization of the model. With these definitions at hand, equation (11) can be transformed into:

$$(18)\quad P_t^i = \frac{1}{1-\beta_t^i + \delta_t^i} \sum^{j} \mu_t^{ji} \; P_{t-1}^j$$

The elements of " and consequently the migration rates are the results of decisions made by the individuals in the system.

In this paper we want to focus on the migration decision, treating birth and death rates as exogenously given. In demographic literature (see for example: Feichtinger, 1973) births and deaths are modeled too.

As is common practice in economics, we assume the migration decision of an individual to be guided by utility maximization. More precisely speaking, we assume that a person will migrate from zone j to zone i, only when it can reach a higher utility level in i than in zone j. Since the individual can make this comparison for every possible terminal zone (including the zone where he now lives), the zone he actually migrates to, must offer the highest utility level of all zones.

So, in a system of n zones,

$$(19)\quad \text{Prob}\,(m^{\cdot i}) = \text{Prob}(U_i > U_k,\ k = 1,\ldots,n)$$

Prob $(m^{\cdot i})$ ... Probability that a person chooses alternative i

Since the individual starts from a given zone j, (19) can be reformulated:

$$(20) \quad \text{Prob}\ (m^{ji}) = \text{Prob}\ (U_i^j > U_k^j,\ k = 1,\dots,n)$$

Prob (m^{ji}) ... Probability that a person in j chooses alternative i

Note that (20) is origin - specific, while (19) is not. Both formulations will be utilized later on.

There is a rapidly growing body of literature, dealing with "random utility models" (Mc Fadden, 1976; Domencich & McFadden, 1975; Hensher & Johnson, 1981; Wegener & Graef, 1982; Anas 1982).

It is a common feature of these models that the utility of an alternative (U) is assumed to be additively separable into a deterministic (V) and a stochastic part (ε).

Ignoring the theoretical controversy about the meaning of these two terms constituting utility, (for a short discussion see Anas, 1982), we can write:

$$(21) \quad \text{Prob}\ (m^{ji}) = \text{Prob}\ (V_i^j + \varepsilon_i^j > V_k^j + \varepsilon_k^j;\ k = 1,\dots,n)$$

or

$$(22) \quad \text{Prob}\ (m^{ji}) = \text{Prob}\ (V_i^j - V_k^j > \varepsilon_k^j - \varepsilon_i^j;\ k = 1,\dots,n)$$

The reformulated statements corresponding to (19) are the right hand sides of (21) and (22) without superscript j.

First let us turn to the deterministic part of utility (V). Following Lancaster (1966) it can be argued that V is a function of the attributes of the zones (C_k^1) and in equations (20), (21), (22) of trip characteristics (C_{ik}^1).

$$(23)\quad V_k^i = V^i(C_k^1,\ldots,\ C_{ik}^1,\ldots)$$

The attributes of all zones contained in the study, can be divided into 3 groups (see v.d. Berg et al., 1981):

1. Living

As in the other two groups, the attributes belonging to this group can be split up into real and price attributes. Real quality of living attributes describe the quantity and quality of housing possibilities in the zone, of recreation, education, environmental quality, cultural and shopping amenities in and around the zone, of social groups in the neighbourhood and so on. Price attributes are land prices, rent levels, level of prices of consumer goods.

2. Working

Most important in this group is the monetary attribute income. Relevant real attributes are security of job, availability of alternative jobs, quality of the job itself, chance of career, etc.

3. Communication

This group consists of all the interaction attributes like costs of information about zones, migration costs, commuting costs (price attributes), disamenities of commuting and other trips (real attributes).

A full list of the operationalized variables actually used in the regressions can be found in table (10). The operationalization ran into the usual data restriction problems. No information for the FUP on land prices and rents was available. As a proxy we used the difference between the "built up area" and the "permanently settled area" ("land reserve"), and population density (residential population / permanently settled area). To capture the capacity of recreational facilities we tried two indicators, i.e. employment in the hotel and restaurant sector and the capacities of skilifts - a rather important variable in a ski resort town such as Innsbruck.

Table 10. List of operational variables in the population models.

		THEORETICAL VARIABLE	LABEL	OPERATIONAL VARIABLE
"Living"				
	Real Attributes	Housing Quality	Quality of Housing	Share of apartments with bathroom and central heating
		Recreational Facilities	Skilift Potential	Potential of capacity of skilifts
		Capacity of Educational System	School Potential	Number of classrooms in high-schools (Potential)
		Environmental Quality	Pollution	Average SO-2 levels
			Noise	Traffic density
		Shopping possibilities	Shopping Potential	Potential of jobs in the commercial sector
	Price Attributes	Land prices	Land Reserve	Difference between built up area and permanently settled area
			Population Density	Number of residential population per square kilometer permanently settled area
"Working"				
	Real Attributes	Job options	Working Potential	Potential of number of jobs
		Income from tourism	Income due to Tourism	Share of beds for tourists in private houses
	Price Attributes	———	———	———
"Communication"				
	Real Attributes	Travel time	(implicit)	Average travel time from-to center of zone in minute
	Price Attributes	———	———	———

Table 11. Regression results of the population models.

VARIABLE	EXP. SIGN	SLM	LIRFM	LORFM
Shopping Potential	+	1.44	--	.66
Hotel Potential	+	--	--	-.87
Skilift Potential	+	.77	.38	.28
Working Potential	+	-.55	.o51	-.2o
School Potential	+	124.2	.o57	54.4
Quality of Housing	+	218.6	.55	1783.2
Income due to Tourism	+	-42.8	--	-68.5
Land Reserve	+	--	.o27	4910.4
Population Density	-	.23	-.oo46	.25
Noise	-	.o53	-.o51	.o62
Pollution	-	.ooo7	-.o15	.ooo2
Constant		--	.o64	.11

For the labor market related variables we could only use income, as no spatially disaggregated figures on unemployment, etc. are available.

Some of these attributes are location specific (i.e. SO-2, noise, population density, quality of housing, income from tourism, land reserve), for others "spatial externalities" are taken into account, as the opportunity to "consume" these is spread over the urban region (jobs, recreation, shopping, schools). We operationalized this concept by computing the appropriate potentials (for the definition of a potential, see e.g. Paelinck and Nijkamp, 1976).

In some applications of random utility models data are observed strictly on the individual level (income, rent, etc.) while in some others these are observed for groups of individuals (average income, average rent) (see: Liaw and Bartels, 1982).

In our study the grouping of individuals had to be based upon the zones of the study area. Therefore, in our case, attributes are average values for the different zones.

Depending on the assumptions about the functional form of the deterministic part of the utility function and about the distribution of the stochastic part, there are different models derivable from the random utility model outlined above (See: Domencich & McFadden, 1975).

The most prominent pair of assumptions is a linear deterministic utility function and a stochastic part independently Weibull distributed. With these assumptions one ends up with the multinominal logit model. For equation (20) the logit formulation is:

$$\text{(24)} \quad \text{Prob}\ (m^{ji}) = \frac{\exp\ (V_i^j)}{\sum^k \exp\ (V_k^j)} = \frac{\exp(\alpha_1^j C_i^1 + \alpha_2^j C_1^2 + \ldots + \alpha_1^j C_{ji}^1 + \ldots)}{\sum^k \exp(\alpha_1^j C_k^1 + \alpha_2^j C_k^2 + \ldots + \alpha_1^j C_{jk}^e + \ldots)}$$

It is easy to see that the axioms of probability theory are fulfilled in this formulation.

The main interest of the analyst concerning this model is to estimate the coefficients (α's) in the deterministic part of the utility function.

To do this, one assumes the coefficients to be the same for all individuals in j. Then an observable migration vector of people in j migrating to the n zones (including j), can be treated as sample of realizations, goverend by (24). By maximum likelihood methods the coefficients can be estimated.

In our sample there is a severe data restriction to this approach. We do not know the full migration matrix, but only the vectors of row- and column- totals (population distribution in t-1 and t). So equation (24) is not directly applicable.

We tried three possible ways out of this dilemma.

1. A simple logit-model (SLM)

2. A linear probability reduced form model (LPRFM)

3. A reduced form logit model (LORFM)

6.1 THE SIMPLE LOGIT MODEL (SLM)

In this model type we simply assume that there are no communication attributes and the individual"s origin zone is of no influence. Migration and information are costless and therefore people are always perfectly informed and in the optimal zone.

The Simple Logit Model starts form equation (19), where the zones are the alternatives an individual can choose from, and the pool of people being in the same decision situation, is the entire population in the system. So the population distribution at t can be interpreted as a sample from the probability distribution.

$$(25)\quad \text{Prob}\ (m^i) = \frac{\exp(V_i)}{\Sigma^k \exp(V_k)} \qquad k = 1,\ldots,n$$

The likelihood of the observed population distribution is given by:

$$(26)\quad L = \prod_{i=1}^{n} \left\{\frac{\exp(V_i)}{\Sigma^k \exp(V_k)}\right\}^{P_i}$$

Substituting a linear function for the deterministic part of the utility function, one ends up with the log-likelihood function (Judge et al, 1980; Wegener & Graef, 1982).

$$(27)\quad \ln\ (L) = \alpha_1\ \Sigma P^i C_i^1 + \alpha_2\ \Sigma P^i C_i^2 + \ldots$$

$$- (\Sigma P^i)(\ln\ \Sigma \exp(\alpha_1 C_i^1 + \alpha_2 C_i^2 + \ldots))$$

which is the basis for maximum likelihood estimation of the parameters.

In the estimation process it turned out that inclusion of all variables leads to a highly correlated data set and therefore to a singular Hessian matrix. Therefore variables had to be eliminated from the data set. Since there are two pairs of variables, which are intended to be alternate proxies for the same attribute one variable of each pair respectively could easily be eliminated. For the variables actually included into the regression, check table (10).

The results of the estimation can be found in table (11).

6.2 THE REDUCED FORM LINEAR PROBABILITY MODEL (LIRFM)

In this model type the communication attribute travel-time is included. A linearized form of the migration probability is used to derivate a reduced form function for population change.

Let the utility of a location (i) of an individual be a linear combination of the attributes of the location:

$$(28) \quad U^i = \Sigma^k \alpha_k C_i^k$$

The probability that this individual will move from location (j) to (i) in a given period of time, given that utility maximisation is the goal, is given by:

$$(29) \quad \text{Prob } (m^{ji}) = \text{Prob } \{(\Sigma^k \alpha_k C_i^k - \Sigma^k \alpha_k C_j^k) > (\varepsilon^j - \varepsilon^i)\}$$

Assume further that the function P can be represented by the following linear probability model:

$$(30) \quad \text{Prob } (m^{ji}) = \Sigma^k \alpha_k (C_i^k - C_j^k)$$

Dropping the assumption of perfect information on all the attributes and assuming individuals to form rational expectations, we have to multiply the attribute differences by an uncertainty discount factor. Hypothesizing further that uncertainty grows with distance from the present location (j), we can formulate a "discount weight function" ϕ^{ij}:

$$(31)\quad \phi^{ij} = f(d^{ij}); \quad 0 \leq f(d^{ij}) \leq 1$$

Equation (30) above can now be transformed to yield:

$$(32)\quad \text{Prob}\ (m^{ji}) \ = \Sigma^k\ \alpha_k (C_k^k - C_j^k)\ \phi^{ij}$$

Interpreting the migration rate μ^{ji} in (15) as the probability to move from (j) to (i) we can substitute (30) into (11), which, after some elementary transformations, yields:

$$(33)\quad P_t^i - P_{t-1} = \Sigma^k \alpha_k (C_i^k \Sigma^j P_t^j - \Sigma^j C_j^k P_t^j) - P_t (1+\beta_t^i - \delta_t^i) - \overline{NM}$$

Equation (33) constitutes a reduced form of (11) (12) (15) above, which can be tested econometrically.

Note that the individual terms on the right hand side of (33) resemble the popular formulation of a "potential", thus producing overlapping spatial spheres of mutual influence. The distance weights assure that the influence of very distant places remains small. In a further step to operationalize the model we made all attributes "relative", by computing percentages of the total volume of an attribute for the whole region and then computing the share of the zones. Furthermore the "utility weights" were constrained to add to unity. (This formulation resembles an approach outlined by Hensher & Johnson (1981, pp 163 - 170), in which the can be interpreted as constant elasticities). A constrained 2-stage-least squares estimation technique was utilized, the results of which are summarized in table (11).

6.3 THE REDUCED FORM LOGIT MODEL (LOREM)

In this model type travel time is a relevant attribute, too. On the basis of the population dynamics function (18) and the Logit formulation (24) a reduced form function for the population in a zone at t is calculated. The Reduced Form Logit Model substitutes the migration probability (24) for the migration rate in the population dynamics function (18).

So

$$(34)\quad P_t^i = \frac{1}{a_t^i}\,\Sigma^j\,\frac{\exp(\alpha_1 C_i^1 + \alpha_2 C_i^2 + \ldots + \alpha_1 C_{ji}^1 + \ldots)\,P_{t-1}^j}{\Sigma^k \exp(\alpha_1 C_k^1 + \alpha_2 C_k^2 + \ldots + \alpha_2 C_{jk}^1 + \ldots)}$$

with $a_t^i = 1 - \beta_t^i + \delta_t^i - \varkappa_t^i$

$\varkappa_t^i$ ... Net inmigration from outside the case study region, relative to P_t^i

Assume specific values for the coefficients in the denumerator as given for a moment, then

$$(35)\quad P_t^i = \frac{1}{a_t^i} \cdot \exp(\alpha_1 C_i^1 + \alpha_2 C_i^2 + \ldots) \cdot K_i$$

$$\text{with } K_j = \Sigma^j \frac{P_{t-1}^j \exp(\bar{\alpha}_1 C_{ji}^1 + \ldots)}{\Sigma^k \exp(\bar{\alpha}_1 C_k^1 + \bar{\alpha}_2 C_k^2 + \quad \bar{\alpha}_1 C_{jk}^1 + \ldots)}$$

$\bar{\alpha}_1$, $\bar{\alpha}_2$,...assumed values of α_1, α_2,

or in logarithmic form:

$$(36)\quad \ln P_t^i - \ln K_i = - \ln a_t^i + \alpha_1 C_i^1 + \alpha_2 C_i^2 + \ldots$$

Equation (36) can be used to estimate the parameters α and ($\ln$ a) with WLS. The observations are weighted with the square roots of P_{t-1}^i. If the estimated values α differ from the ones assumed in the K_j s, the estimated coefficients can be used to recalculate the K_j s, in a second step. These iterations should be continued until the assumed and the estimated coefficients are sufficiently equal.

Note that the coefficients of the communication attributes cannot be computed by means of this iterative procedure. We have to assume a priori values for these coefficients. As it turns out, the estimated coefficient values are not very sensible to changes in the coefficients of the communication attributes. The results of the estimation can be found in table (11). For the communication attribute the following function was assumed

$$f(d_{ij}) = \begin{cases} 1 & \text{when } i = j \\ \exp(-4.5 - 0.048\, d_{ij}) & \text{when } i \neq j \end{cases}$$

Some remarks about the treatment of "accessibility" have to be added. We used the approximate travel time from zone (i) to (j) as an attribute to asess the importance of accessibility. In the LIREM, aggregation yields a "population potential", when the distance decay function $f(d_{ij})$ is used instead of the distance directly.

The SLM does not contain a distance friction term at all, due to its nature, while the LOREM utilizes $f(d_{ij})$, as mentioned. It does not, however, appear as a separate variable, so that its influence cannot be assessed directly.

6.4 RESULTS OF THE ESTIMATION

In the discussion of the results of the various approaches let us use 4 criteria to evaluate the suitability of the chosen model for the problem at hand.

The first criterion concerns the significance of the parameter estimates in terms of their t-values (which can be used only as an approximation to the true values).

The logit model in both versions produces substantially higher t-values for all variables, while the LIREM fares badly on this count. Which variables seem to be most significant in these chosen approaches? Table (12) presents an overview, generally speaking there seems to be no clear pattern. The two logit-model based regressions show a similar ranking. It is striking to note how significant the SO-2 variable turns out to be in the SLM and LOREM, as opposed to the LIREM. The recreation variable proxy seems to rank about equally high in all formulations. The quality of housing variable bounces around considerably. In the LIREM it turns out to be the most significant variable, in the LOREM it ranks third, while in the SLM it turns out to be the least significant.

The school potential fares about the same in all approaches, it represents good middle class. The working potential ranks fairly high throughout, particularly in the logit based formulations.

Turning to the signs of the parameters next, we observe that the results exhibit a wide variety of conformity with expectations. The LIREM (after some experimentation, of course) produces the best possible result, i. e. all parameters have

Table 12. Ranking of t-values and standardized coefficients (c)

VARIABLE	SLM t	SLM c	LIRFM t	LIRFM c	LORFM t	LORFM c
Shopping Potential	1	3	-	-	10	4
Hotel Potential	-	-	-	-	8	5
Skilift Potential	3	4	2	2	4	6
Working Potential	2	1	4	4	1	1
School Potential	4	2	3	3	6	3
Quality of Housing	9	8	1	1	3	7
Income due to Tourism	7	7	-	-	5	9
Land Reserve	-	-	7	6	11	2
Population Density	5	9	5	8	9	11
Noise	8	6	8	5	7	8
Pollution	1	5	6	7	2	10

the expected signs. The two logit based models conform to about roughly 50 percent with expectations. The most striking feature of these models is the consistency of positive signs of the pollution variables and the negative sign of the employment opportunities (this happened in practically all variants tried).

The comparison of the magnitude of the influence of the attributes poses problems of different scale.

In the LIRFM the attributes are all standardized, so that the regression coefficients can be directly compared. They could be interpreted as the "demand side" influence on urban development, as they are directly related to houshold utility. (For an overview see table (12)). In this model the quality of housing and recreation facilities turn out to be the most important decision variables in terms of housnold"s utility, while environmental quality seems to count less.

The total effect of a variable on population change, has to consider the attribute differences, absolute size of the population and the accessibility structure as well (see equation (33)). Inspection of the spatial distributions of the various attributes indicate pronounced differences in the environmental quality variables and much more even distributions of the infrastructure as well as housing attributes. Hence, environmetal quality in the 1971-1981 decade could have played more role considering "supply" and "demand" factors together than indicated by the magnitude of the coefficients only.

It should be mentioned that the results of the LIRFM correspond roughly to the ranking established by a survey undertaken by the city administration of Innsbruck. The low influence assigned by this model to "accessibility", although perhaps contrary to expectations by an urban economist, is corroborated by the survey results (Amt der Tiroler Landesregierung, 1981).

It is noteworthy, that the ranking of the attribute weights is practically identical in the SLM and LOREM. Elasticities were computed (for the averages of the attributes over the FUR) to compare the total impact of changes of attributes. The demand factors, i.e. the coefficients as such, cannot be compared across variables, as they are not standardized.

As can be seen from table (12), the logit based models place the working opportunities and the land reserves (i.e. indirectly land prices) on the top of the scale while the quality of housing seems to be rather insignificant in influence. Both models show a comparatively low influence of environmental quality variables, infrastructure - particularly schools - are approximately equal in rank.

All three models permit the estimation of migration matrices and population vectors. Because of the lack of an observed migration matrix, we can base tests strictly speaking only on the population vector. However, the estimated migration matrices can be checked for plausibility of their elements.

Due to the mathematics of the LIREM, this model produces the worst results. The estimated migration matrix contains some negative values. This is inconsistent with the definition of migration rates. On the other hand, the SLM does not contain a distance friction term at all. Although all the elements in the migration matrix are between zero and one and sum up to one for each row, they are exactly the same for each row. Only the LORFM produces a migration matrix, which is consistent with the definition of migration rates (between zero and one and summing up to unity over each row) and allows variation over the rows. In the specification presented above, the LORFM produces a migration matrix, where sixty to ninety-five percent of residents of a zone in (t-1) remain in that zone, which is a plausible result.

Based on the estimated migration matrices population vectors for time (t) can be estimated. Regression of the observed population on the estimated figures for SLM and LORFM yields the following results (see table (13)).

Table 13. Regression results of relation between estimated and actual population in the Innsbruck FUR.

	SLM	LORFM
R-square	.9841	.9992
Intercept	223.84 (220.95)	-4.81 (53.95)
Slope	.9398 (.0150)	1.004 (.0037)

Values in parathenses are standard errors

Both models explain a high percentage of the observed population distribution, nevertheless, on this criterion the LORFM is clearly superior to the SLM.

7.0 SUMMARY AND CONCLUSIONS

The biggest drawback of the presented analysis is the lack of data for direct tests of validity. The environmental quality information available cannot be used as such in a feedback model of the kind described. Further work to bring together different approaches seems warranted. Lack of spatially disaggregated fuel consumption data is another obstacle to reliable empirical work in this field. Although the estimates made do not seem too far fetched, the state of the art could be greatly improved. A real dynamic analysis, of course, cannot rely on constant energy input coefficients. An attempt to go beyond the nationally based study by Schmoranz (1983), introducing regional supply (and other specific) factors would seem worth the researchers while. Similar observations can be made on the environmental section of the study. Emission coefficients, we know, depend on environmental policy measures. But data to verify this claim are virtually non existent. Another serious deficiency is the absence of an explicit relation between the environment and the spatial distribution of firms over the urban region. It is not only the lack of environmental data, but generally the absence of zonal, economic data which prevent such an analysis.

A disturbing fact concerning the results of the population submodel is the variation in the results. More work seems badly needed to be able to recommend any particular method. From the estimation point of view, the SLM, for which a maximum likelihood method can be used, is the most attractive. The LIRFM produces acceptable results from an a-priori point of view, which in this case coincide with some survey based information. The LORFM starts from the least restrictive set of assumptions. (The prespecification of the distance decay function appears to be rather harmless.) The estimation technique, via an iterative LS based procedure is not very satisfactory. Maximum Likelihood methods on the reduced form (Wegener, forthcoming) run into problems with natural population change.

In the cross-section based modeling strategy, urban development, in the long run turns out to be "supply side" driven, as it is the relative attributes (in whatever form specified) that change over time, while the constant coefficients, representing the "demand side" (utility), remain passive. It seems unlikely, however, that this constancy is a fact of life, but unfortunately not enough long run longitudinal data are available to ammend this unsatisfactory situation. Whether this problem can be overcome by comparison of urban regions in different development stages still remains an open question, although there is some evidence that this may be the case (Schubert, forthcoming).

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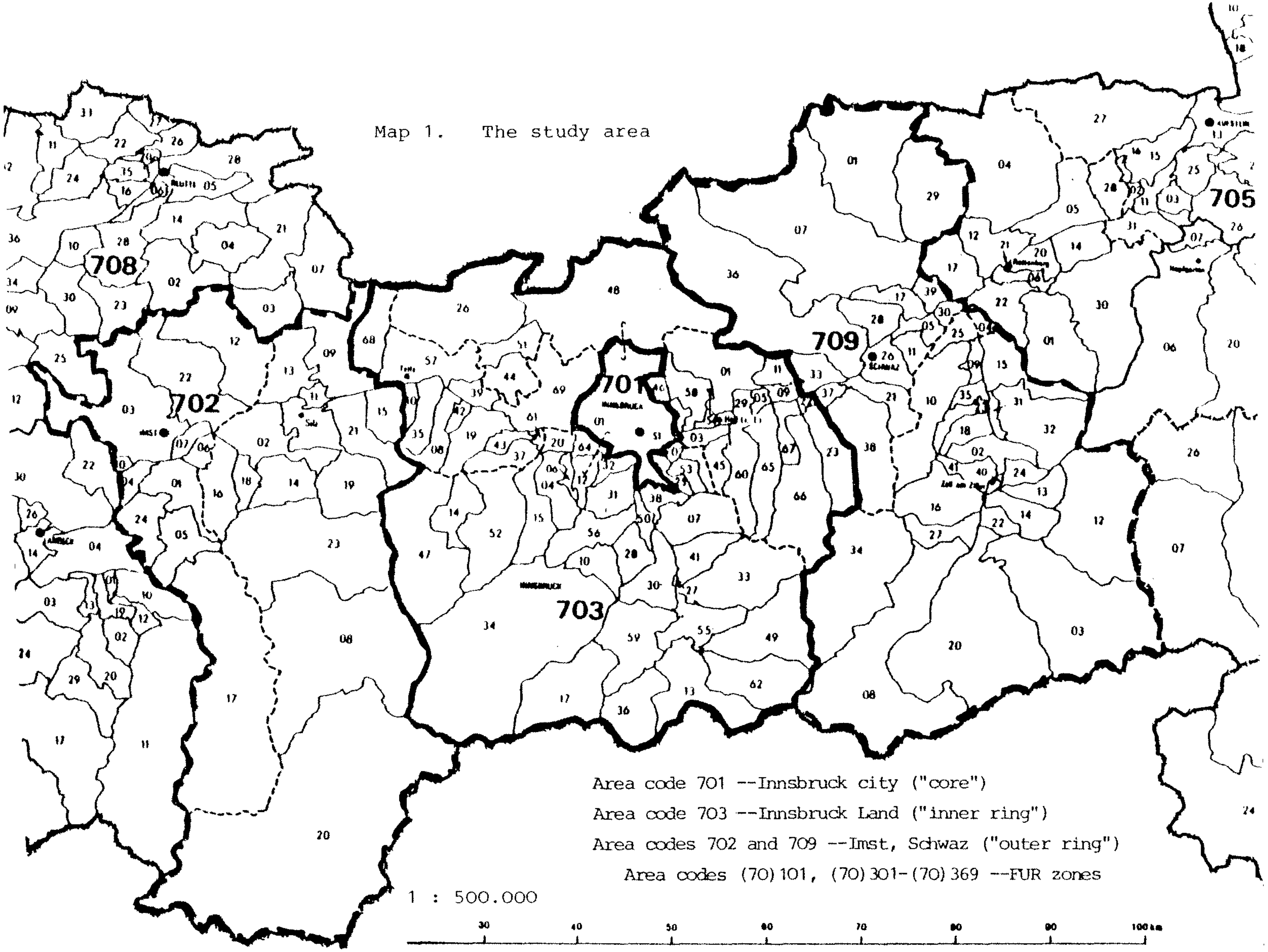
A P P E N D I X



Map 1. The study area

Table 1. Net production values (NPV) in the Innsbruck FUR by zone 1976

101	12437307.8	326	66199.0	348	53372.0
301	239907.8	327	87039.4	349	21219.9
302	31780.5	328	31517.3	350	72739.4
303	14661.5	329	91576.4	351	253722.6
304	88181.8	330	49089.2	352	20536.5
305	8138.4	331	59050.0	353	22284.8
306	18445.9	332	46769.4	354	1224756.9
307	16402.5	333	45666.4	355	137287.5
308	28821.6	334	124008.5	356	36216.6
309	67680.8	335	36217.4	357	499746.5
310	256134.8	336	18006.7	358	68250.5
311	15106.3	337	43419.2	359	23806.6
312	40872.1	338	21743.9	360	27319.5
313	79197.2	339	14493.1	361	5377.3
314	15888.4	340	98793.4	362	12868.2
315	10286.7	341	29582.8	364	129303.3
317	8643.4	342	7104.9	365	65687.5
319	158053.0	343	6168.7	366	12765.1
320	71339.6	344	37478.4	367	946024.5
322	42317.6	345	21405.0	368	17845.1
323	11962.9	346	406604.1	369	206798.3
325	23283.0	347	9294.8		

Source: Computations by the authors

Table 4. The determinants of automobile traffic
(traffic desity in the Innsbruck FUR)

MULTIPLE R	.7075	ANOVA	DF	SUM SQUARES	MEAN SQ.	F
R SQUARE	.5006	REGRESSION	2.	.5941E+09	.19E+09	17.710
STD DEV	3344.1778	RESIDUAL	53.	.5927E+09	.11E+08	SIG. 0
ADJ R SQUARE	.4723	COEFF OF VARIABILITY		61.4PCT		

VARIABLE	B	S.E. B	F	SIG.	BETA	ELASTICITY
PENDLER	3.088	.729	17.921	.000	.57215	.28991
WBPOT	.077	.071	1.171	.284	.72380	1.15879
CONSTANT	2677.055	1148.483	5.433	.024		

DEFINITION OF VARIABLES:

PENDLER ..... NUMBER OF COMMUTERS
WBPOT ..... POPULATION POTENTIAL

Source: Computations by authors

Table 3. Fuel consumption in the Innsbruck FUR (Estimates for coal, oil and wood used in 1976 for all 65 zones of the study region).

101	159272.30	141461.47	23434.02
301	2191.48	3169.03	468.82
302	597.77	289.46	102.71
303	517.45	67.23	80.58
304	2318.34	1096.46	312.49
305	309.62	59.85	60.53
306	395.22	145.22	56.60
307	541.19	104.18	73.44
308	802.14	359.65	86.42
309	1271.26	1589.30	198.12
310	2223.78	1834.57	295.84
311	333.68	142.87	33.13
312	889.31	345.60	198.31
313	1415.70	843.49	126.53
314	297.53	136.33	38.41
315	402.61	92.60	76.12
317	238.19	86.96	30.85
319	1848.26	1232.37	360.42
320	1575.05	1140.98	186.44
322	1146.37	468.38	148.39
323	471.31	42.61	35.36
325	369.27	282.00	50.84
326	1075.36	683.11	135.29
327	693.27	552.77	99.68
328	417.35	319.34	71.83
329	1215.62	763.04	215.74
330	1658.06	793.10	161.79
331	793.31	453.59	130.33
332	733.24	712.34	102.77
333	1010.47	2000.23	137.89
334	1787.78	1132.85	256.13
335	581.90	601.40	85.09
336	554.82	95.28	24.90
337	907.90	188.74	128.51
338	1243.25	292.09	55.57
339	407.09	117.11	84.80
340	614.55	3697.99	98.15
341	601.13	188.46	74.52
342	235.62	96.07	37.39
343	242.11	37.85	41.11
344	366.69	422.30	64.47
345	625.41	231.56	71.57
346	3662.50	6340.98	876.23
347	220.64	101.25	11.04
348	572.50	561.28	107.65
349	836.14	44.31	59.95
350	3393.08	1384.00	247.52
351	1923.76	2847.65	237.04
352	578.82	161.04	90.95
353	448.15	156.69	65.32
354	57357.19	16685.23	1557.02
355	1909.88	1203.40	289.12
356	476.14	261.81	73.73
357	5529.33	19135.05	918.17
358	1183.80	422.80	344.19
359	576.46	227.56	67.23
360	616.96	285.59	66.29
361	162.48	72.16	16.11
362	378.62	75.19	37.78
364	1772.18	1700.42	392.09
365	1743.29	509.98	240.51
366	496.58	56.91	36.79
367	8482.69	27701.35	2328.57
368	500.01	154.72	42.35
369	6235.84	3272.46	690.85

Source: Computations by the authors

Table 5. Emission coefficients for SO_2 for 3 types of fuel.

Fuel	total	Power plants, remote heating	Social and technical infrastructure	Industry (large scale)	Small scale industry, manufacturing, offices	Agriculture	Wholesaling, retailing	Households
Solid fossil fuels	.01802	.01462	.01442	.24000	.01885	.01714	.01452	.01813
Oil - light	.02903	0.00000	.05918	.01333	.01356	.01379	.01400	.01139
Oil - medium	.04555	0.00000	.03053	.02100	.02799	.02147	.02109	0.00000
Oil - heavy	.04636	.04694	.04545	.04583	.03038	.04889	.04611	0.00000
Garbage	.00277	.00285	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Natural gas	.00003	.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

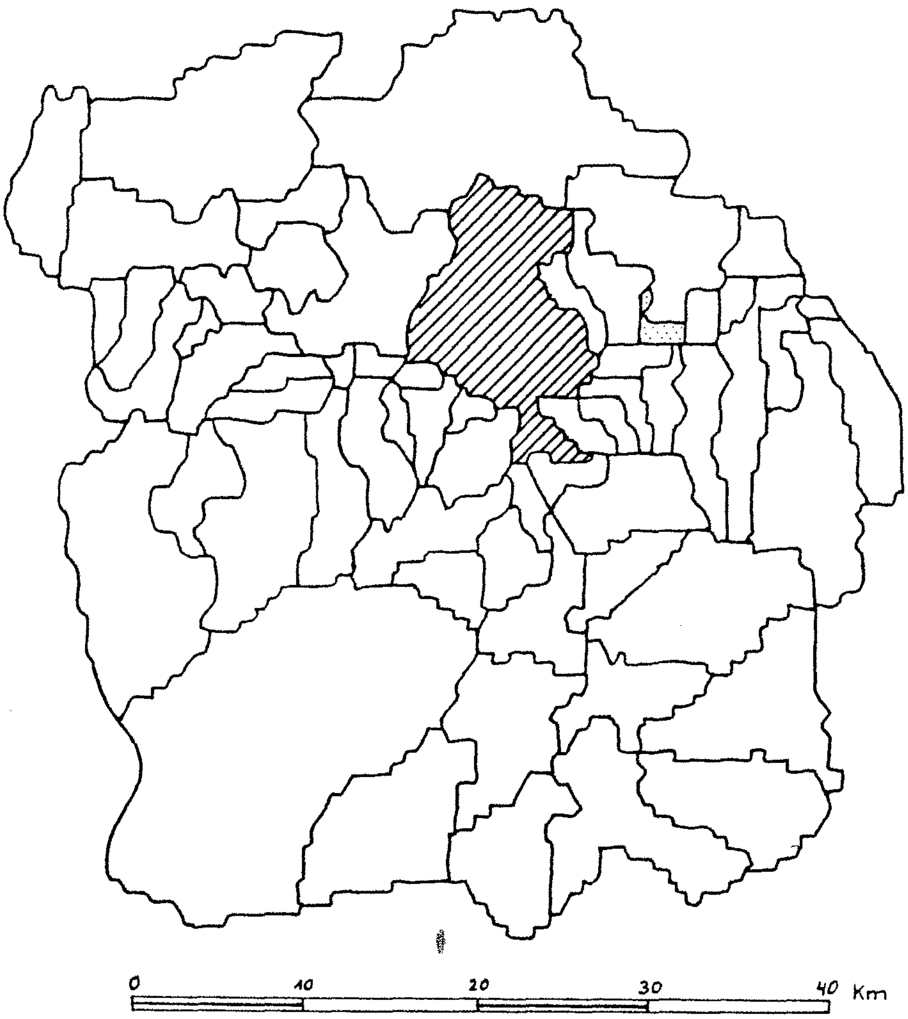
Source: Computations by the authors, based on "Emissionskataster für Wien" (OeStZ,1978)

Table 7. SO_2 emissions in the Innsbruck FUR.

101	7360.27495	326	33.16921	348	21.77639
301	165.62031	327	28.83857	349	15.66469
302	17.23986	328	17.74955	350	105.90733
303	11.07388	329	41.38421	351	86.38165
304	69.08737	330	58.52796	352	15.98827
305	7.01137	331	25.98941	353	12.15328
306	11.40398	332	31.48415	354	1962.83723
307	11.98572	333	107.85052	355	66.11931
308	29.05361	334	54.41239	356	13.36087
309	93.36331	335	36.57173	357	929.28743
310	95.08176	336	10.94939	358	36.79192
311	8.18531	337	21.67117	359	14.06789
312	26.43234	338	36.10014	360	17.95079
313	42.72865	339	10.41808	361	5.20935
314	7.33100	340	175.74723	362	8.85390
315	9.65271	341	15.65311	364	107.66295
317	5.53162	342	8.22180	365	47.88862
319	82.85157	343	5.34738	366	9.66262
320	66.65704	344	16.76114	367	1418.36276
322	37.79229	345	16.68355	368	14.11801
323	9.09483	346	331.95639	369	217.88838
325	10.85469	347	5.09805		

Source: Computations by the authors

Map 3. SO_2 emissions in the Innsbruck FUR



	more than 5400
	.... 3600 to 5400
	.... 1800 to 3600
	less than 1800

Source: Computations by the authors

Table 8. Steady state diffusion coefficients for the Innsbruck FUR.

[illegible]	540.0	220.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0
	417.0	0.0	0.0	0.0	222.9	0.0	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
301	0.0	540.0	0.0	0.0	0.0	556.5	0.0	0.0	0.0	440.5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	317.3
	9.2	0.0	0.0	0.0	0.0	645.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	156.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	240.0	0.0	0.0	0.0	263.0	0.0	0.0	0.0	0.0	0.0
	517.3	[illegible]	425.9	0.0	0.0					
302	50.7	322.6	540.0	713.1	0.0	274.1	0.0	0.0	0.0	258.1
	0.0	136.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	242.7
	146.6	0.0	0.0	0.0	0.0	325.2	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	13.5	384.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	389.9	0.0	0.0	0.0	338.2	0.0	22.8	0.0	0.0	0.0
	308.3	151.0	278.9	0.0	0.0					
303	132.3	394.1	190.8	540.0	0.0	303.5	0.0	0.0	0.0	284.3
	0.0	49.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	265.4
	129.7	0.0	0.0	0.0	0.0	391.5	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	7.4	52.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	529.0	0.0	0.0	0.0	419.2	0.0	9.8	0.0	0.0	0.0
	363.7	124.9	303.5	0.0	0.0					
304	291.2	199.0	279.6	263.6	540.0	183.3	655.2	0.0	0.0	177.1
	0.0	173.8	707.0	0.0	0.0	15.7	0.0	0.0	64.4	169.7
	169.7	304.7	0.0	0.0	0.0	195.3	0.0	393.7	435.0	0.0
	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	229.1	236.7	0.0	0.0	0.0	0.0	0.0	0.0	270.4
	216.1	0.0	0.0	0.0	217.9	0.0	207.5	0.0	0.0	585.2
	189.8	183.6	181.5	0.0	0.0					
305	0.0	55.8	0.0	0.0	0.0	540.0	0.0	0.0	0.0	656.4
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.5
	0.0	0.0	0.0	0.0	0.0	160.1	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	540.0	0.0	667.1	0.0	0.0					
306	327.0	217.1	297.5	282.9	301.6	189.9	540.0	0.0	0.0	183.6
	0.0	179.0	577.2	0.0	0.0	3.7	0.0	0.0	112.2	176.2
	174.7	336.9	0.0	0.0	0.0	205.9	0.0	437.6	583.3	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	189.7	256.9	0.0	0.0	0.0	0.0	0.0	0.0	203.6
	236.2	0.0	0.0	0.0	233.1	0.0	176.4	0.0	0.0	657.5
	196.2	183.2	187.9	0.0	0.0					
307	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0
	0.0	0.0	0.0	117.1	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	299.9	0.0	0.0	369.9	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	10.4	0.0	0.0	379.3	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	206.6	0.0	0.0	0.0
	0.0	218.6	0.0	0.0	0.0	0.0	0.0	0.0	46.7	0.0
	0.0	0.0	0.0	0.0	0.0					
308	195.1	174.1	142.8	151.5	32.4	157.9	41.5	0.0	540.0	151.4
	0.0	55.6	38.2	0.0	0.0	5.2	0.0	503.1	275.1	140.7
	61.1	53.0	0.0	0.0	0.0	166.7	0.0	67.6	143.4	0.0
	0.0	142.0	0.0	139.4	0.0	786.3	146.7	0.0	692.6	124.6
	0.0	45.7	185.4	0.0	0.0	0.0	0.0	0.0	0.0	40.8
	174.4	0.0	0.0	5.2	183.1	0.0	47.2	295.3	0.0	232.9
	157.3	59.9	150.1	0.0	339.6					
309	0.0	0.0	0.0	0.0	0.0	243.3	0.0	0.0	0.0	540.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	689.5
	0.0	0.0	0.0	0.0	0.0	30.6	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	103.9	0.0	657.0	0.0	0.0					
310	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	583.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	203.6	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	197.6	0.0	0.0	0.0
	0.0	0.0	201.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
311	0.0	0.0	0.0	0.0	0.0	625.1	0.0	0.0	0.0	689.7
	0.0	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	426.1
	359.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	395.0	293.1	419.5	0.0	0.0					
312	345.5	224.8	320.4	292.9	234.5	192.7	421.2	0.0	0.0	186.5
	0.0	182.2	540.0	0.0	0.0	0.0	0.0	0.0	61.3	179.3
	178.8	369.8	0.0	0.0	0.0	214.5	0.0	488.0	592.3	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	252.7	264.2	0.0	0.0	0.0	0.0	0.0	0.0	383.5
	244.9	0.0	0.0	0.0	245.0	0.0	185.6	0.0	0.0	686.7
	199.4	192.6	191.0	0.0	0.0					
313	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	540.3	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	121.3	0.0
	0.0	0.0	0.0	0.0	0.0					
314	0.0	0.0	0.0	0.0	299.5	0.0	279.3	0.0	0.0	0.0
	0.0	0.0	270.0	0.0	540.0	336.9	0.0	0.0	0.0	0.0
	0.0	196.2	0.0	0.0	0.0	0.0	0.0	240.3	214.3	0.0
	0.0	0.0	0.0	247.5	0.0	0.0	0.0	0.0	0.0	279.6
	0.0	176.0	0.0	0.0	0.0	0.0	0.0	0.0	526.8	192.5
	0.0	0.0	0.0	0.0	0.0	0.0	167.4	0.9	0.0	0.0
	0.0	146.0	0.0	0.0	0.0					
315	273.9	193.5	258.4	243.7	666.5	177.5	650.6	0.0	0.0	171.2
	0.0	170.4	562.7	0.0	0.0	540.0	0.0	0.0	528.6	163.5
	163.9	280.0	0.0	0.0	0.0	189.4	0.0	347.2	395.0	0.0
	0.0	0.0	0.0	36.4	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	221.7	220.3	0.0	0.0	0.0	0.0	0.0	42.2	267.4
	199.3	0.0	0.0	0.0	202.3	0.0	198.9	449.7	0.0	431.9
	183.5	177.6	175.1	0.0	0.0					
317	0.0	0.0	0.0	0.0	0.0	0.0	0.0	169.6	0.0	0.0
	0.0	0.0	0.0	337.5	0.0	0.0	540.0	0.0	0.0	0.0
	0.0	0.0	0.0	221.4	0.0	0.0	198.2	0.0	0.0	149.4
	0.0	0.0	117.3	0.0	0.0	0.0	0.0	194.1	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	53.8	0.0	0.0	0.0	0.0
	0.0	281.2	0.0	0.0	0.0	350.1	0.0	0.0	273.7	0.0
	0.0	0.0	0.0	0.0	0.0					
319	238.3	187.4	126.3	139.8	2.2	172.3	13.7	0.0	0.0	165.6
	0.0	16.1	3.2	0.0	0.0	0.0	0.0	540.0	330.0	155.4
	25.4	27.3	0.0	0.0	0.0	181.9	0.0	31.6	50.1	0.0
	0.0	0.0	0.0	9.4	0.0	81.6	0.0	0.0	215.7	2.8
	0.0	0.0	202.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	190.3	0.0	0.0	0.0	196.2	0.0	0.0	455.6	0.0	289.7
	173.1	21.6	165.5	0.0	558.0					

Table 8. (cont.)

320	319.4	214.7	126.7	146.2	0.0	189.8	1.4	0.0	0.0	183.2
	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	510.0	174.5
	15.9	2.4	0.0	0.0	0.0	203.4	0.0	13.9	27.8	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	256.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	232.6	0.0	0.0	0.0	236.9	0.0	0.0	327.5	0.0	572.3
	193.6	10.9	105.6	0.0	99.9					
322	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	191.7
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	166.4	0.0	0.0					
323	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	291.4
	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	45.7	173.0	0.0	0.0					
325	0.0	270.9	719.9	491.6	0.0	242.5	0.0	0.0	0.0	226.6
	0.0	204.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	212.1
	216.1	540.0	0.0	0.0	0.0	279.1	0.0	61.3	112.2	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	391.4	319.4	0.0	0.0	0.0	0.0	0.0	0.0	154.9
	315.9	0.0	0.0	0.0	287.0	0.0	220.3	0.0	0.0	0.0
	272.5	262.3	248.2	0.0	0.0					
326	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	399.3	0.0	0.0	203.3	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
327	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	50.6	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	540.0	0.0	0.0	242.4	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	483.1	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	221.5	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0
	0.0	0.0	0.0	0.0	0.0					
328	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	146.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	540.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	339.9	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	205.9	0.0	0.0	0.0
	0.0	0.0	268.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
329	0.0	227.3	0.0	0.0	0.0	669.3	0.0	0.0	0.0	522.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	395.9
	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	233.6	0.0	0.0	0.0	65.7	0.0	0.0	0.0	0.0	0.0
	717.1	0.0	559.0	0.0	0.0					
330	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	51.6	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	683.8	0.0	0.0	540.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	156.7	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	289.9	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0
	0.0	0.0	0.0	0.0	0.0					
331	330.4	228.2	384.9	321.4	0.0	196.2	0.0	0.0	0.0	190.0
	0.0	151.2	15.1	0.0	0.0	0.0	0.0	0.0	0.0	185.0
	160.7	448.6	0.0	0.0	0.0	225.5	0.0	540.0	249.8	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	185.0	262.0	0.0	0.0	0.0	0.0	0.0	0.0	178.0
	254.3	0.0	0.0	0.0	241.3	0.0	174.1	0.0	0.0	0.0
	217.1	173.6	197.6	0.0	0.0					
332	394.1	250.5	435.4	365.9	0.0	207.7	0.0	0.0	0.0	196.7
	0.0	140.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	198.7
	147.0	171.8	0.0	0.0	0.0	244.9	0.0	522.4	540.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	141.4	286.5	0.0	0.0	0.0	0.0	0.0	0.0	119.6
	274.7	0.0	0.0	0.0	266.0	0.0	135.0	0.0	0.0	67.7
	232.9	197.8	207.8	0.0	0.0					
333	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	201.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
334	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	358.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	203.7	0.0	0.0	0.0	0.0	0.0
	540.0	0.0	0.0	0.0	193.1	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	236.6	0.0	0.0	0.0
	0.0	0.0	291.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
335	164.7	167.7	115.4	126.0	0.0	158.9	12.2	0.0	271.0	134.5
	0.0	24.6	31.9	0.0	0.0	0.0	0.0	154.6	215.2	113.5
	35.1	44.9	0.0	0.0	0.0	154.7	0.0	52.1	66.6	0.0
	0.0	540.0	0.0	33.4	0.0	544.3	301.5	0.0	452.4	22.1
	0.0	18.3	176.9	0.0	0.0	0.0	0.0	0.0	0.0	15.0
	165.7	0.0	0.0	270.7	174.4	0.0	37.0	255.9	0.0	190.3
	149.0	32.0	142.1	0.0	279.4					
336	0.0	0.0	0.0	0.0	0.0	0.0	0.0	149.7	0.0	0.0
	0.0	0.0	0.0	444.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	169.4	0.0	0.0	179.9	0.0	0.0	182.5
	0.0	0.0	540.0	0.0	0.0	0.0	0.0	176.6	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	242.7	0.0	0.0	0.0	0.0
	0.0	242.6	0.0	0.0	0.0	268.4	0.0	0.0	331.9	0.0
	0.0	0.0	0.0	0.0	0.0					
337	274.3	195.7	242.2	235.5	215.0	179.0	384.7	0.0	0.0	172.4
	0.0	139.4	221.6	0.0	0.0	130.1	0.0	0.0	698.9	163.5
	134.5	189.9	0.0	0.0	0.0	190.2	0.0	275.5	299.5	0.0
	0.0	0.0	0.0	540.0	0.0	0.0	0.0	0.0	0.0	298.2
	0.0	149.9	227.0	0.0	0.0	0.0	0.0	0.0	0.0	156.8
	199.7	0.0	0.0	0.0	212.0	0.0	142.4	709.6	0.0	408.9
	182.7	142.8	174.6	0.0	588.1					
338	0.0	0.0	0.0	0.0	0.0	0.0	0.0	413.7	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	237.6	0.0	0.0	267.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	540.0	0.0	0.0	255.7	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	109.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
339	205.7	188.5	117.8	130.5	4.5	166.5	21.3	0.0	19.1	160.0
	0.0	16.5	5.7	0.0	0.0	0.0	0.0	535.6	285.6	149.2
	27.3	13.3	0.0	0.0	0.0	174.9	0.0	39.5	54.7	0.0
	0.0	70.5	0.0	17.3	0.0	540.0	0.0	0.0	205.8	11.6
	0.0	0.0	192.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	182.3	0.0	0.0	0.0	189.4	0.0	0.0	315.6	0.0	243.6
	165.4	24.4	158.3	0.0	363.6					

Table 8. (cont.)

340	182.0	162.6	121.9	131.4	33.0	146.7	36.5	0.0	528.5	140.2
	0.0	38.0	36.5	0.0	0.0	2.4	0.0	351.0	233.0	129.3
	56.2	51.0	0.0	0.0	0.0	154.9	0.0	59.0	119.6	0.0
	0.0	646.1	0.0	45.3	0.0	488.9	540.0	0.0	453.6	32.9
	0.0	22.8	173.3	0.0	0.0	0.0	0.0	0.0	0.0	19.1
	162.2	0.0	0.0	277.2	171.5	0.0	24.2	253.3	0.0	197.0
	145.3	54.9	138.3	0.0	275.0					
341	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	135.9	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	162.4	0.0	0.0	386.8	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	525.7	0.0	0.0	0.0	0.0	0.0	0.0	33.2	0.0
	0.0	0.0	0.0	0.0	0.0					
342	208.1	178.8	121.2	133.5	3.9	163.9	19.0	0.0	28.5	157.2
	0.0	19.0	5.2	0.0	0.0	0.0	0.0	715.1	304.0	146.8
	28.8	12.8	0.0	0.0	0.0	173.1	0.0	37.5	55.3	0.0
	0.0	0.0	0.0	15.3	0.0	712.4	0.0	0.0	540.0	0.0
	0.0	0.0	191.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	181.2	0.0	0.0	0.0	187.6	0.0	0.0	351.5	0.0	257.5
	164.0	25.4	156.5	0.0	392.5					
343	261.6	192.7	225.5	221.0	338.5	176.0	349.0	0.0	0.0	169.3
	0.0	142.0	321.6	0.0	0.0	163.0	0.0	103.3	567.2	168.0
	135.2	225.2	0.0	0.0	0.0	186.8	0.0	261.0	279.9	0.0
	0.0	0.0	0.0	658.7	0.0	0.0	0.0	0.0	0.0	540.0
	0.0	152.6	217.3	0.0	0.0	0.0	0.0	0.0	0.0	160.4
	196.0	0.0	0.0	0.0	233.7	0.0	145.7	677.4	0.0	364.4
	178.9	143.3	170.8	0.0	634.6					
344	243.2	196.2	196.9	199.7	253.3	180.3	259.2	0.0	0.0	173.8
	0.0	180.5	252.1	0.0	0.0	261.1	0.0	64.1	315.9	162.9
	159.5	196.0	0.0	0.0	0.0	188.5	0.0	198.2	219.9	0.0
	0.0	0.0	0.0	328.0	0.0	146.4	0.0	0.0	34.3	0.0
	540.0	187.0	220.8	0.0	0.0	0.0	0.0	0.0	0.0	193.2
	195.6	0.0	0.0	0.0	215.6	0.0	182.0	364.4	0.0	274.5
	178.9	165.3	171.9	0.0	457.0					
345	0.0	[illegible]	179.7	154.7	0.0	271.9	0.0	0.0	0.0	241.0
	0.0	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	271.8
	208.6	0.0	0.0	0.0	0.0	166.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.4
	540.0	0.0	0.0	0.0	0.0	0.0	671.5	0.0	0.0	0.0
	378.9	372.1	317.2	0.0	0.0					
346	64.4	600.0	0.0	138.6	0.0	374.1	0.0	0.0	0.0	326.0
	0.0	.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	282.3
	2.0	0.0	0.0	0.0	0.0	585.2	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	695.0	0.0	0.0	0.0	615.6	0.0	0.0	0.0	0.0	0.0
	386.6	1.7	332.5	0.0	0.0					
347	0.0	0.0	0.0	0.0	278.3	0.0	251.1	0.0	0.0	0.0
	0.0	0.0	241.0	0.0	591.3	298.1	0.0	0.0	0.0	0.0
	0.0	184.6	0.0	0.0	0.0	0.0	0.0	201.9	208.0	0.0
	0.0	0.0	0.0	277.7	0.0	0.0	0.0	0.0	0.0	276.4
	0.0	164.7	0.0	540.0	0.0	0.0	0.0	0.0	380.4	180.7
	0.0	0.0	0.0	0.0	0.0	0.0	156.3	0.0	0.0	0.0
	0.0	134.0	0.0	0.0	0.0					
348	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	540.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
349	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
350	0.0	0.0	0.0	0.0	0.0	0.0	0.0	623.3	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	279.4	153.7	0.0	319.4	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	596.5	0.0	0.0	309.4	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0	0.0
	0.0	0.0	83.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
351	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	277.4	0.0	0.0	540.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
352	0.0	0.0	0.0	0.0	459.7	0.0	381.9	0.0	0.0	0.0
	0.0	0.0	361.5	0.0	0.0	504.5	0.0	0.0	0.0	0.0
	0.0	243.8	0.0	0.0	0.0	0.0	0.0	293.1	267.6	0.0
	0.0	0.0	0.0	376.7	0.0	0.0	0.0	0.0	0.0	345.0
	0.0	192.5	0.0	0.0	0.0	0.0	0.0	0.0	540.0	226.1
	0.0	0.0	0.0	0.0	0.0	0.0	183.6	0.0	0.0	0.0
	0.0	163.4	0.0	0.0	0.0					
353	0.0	281.6	700.1	503.5	0.0	248.1	0.0	0.0	0.0	233.0
	0.0	212.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	220.2
	228.4	410.8	0.0	0.0	0.0	284.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	547.8	318.9	0.0	0.0	0.0	0.0	0.0	0.0	540.0
	324.5	0.0	0.0	0.0	208.1	0.0	403.4	0.0	0.0	0.0
	279.8	279.8	256.1	0.0	0.0					
354	0.0	194.5	0.0	0.0	0.0	430.5	0.0	0.0	0.0	385.5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	327.6
	0.0	0.0	0.0	0.0	0.0	598.4	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	120.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	540.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0
	545.0	0.0	415.1	0.0	0.0					
355	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	157.5	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	540.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0
	0.0	0.0	0.0	0.0	0.0					
356	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	207.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	633.3	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	363.4	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	507.8	0.0	0.0	0.0
	0.0	0.0	540.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0					
357	177.0	159.4	115.5	125.2	35.1	143.9	38.7	0.0	482.2	137.6
	0.0	29.2	33.4	0.0	0.0	3.4	0.0	300.1	212.0	126.5
	55.1	51.3	0.0	0.0	0.0	151.5	0.0	59.0	112.7	0.0
	0.0	674.8	0.0	44.2	0.0	417.3	656.9	0.0	373.7	31.9
	0.0	23.3	169.6	0.0	0.0	0.0	0.0	0.0	0.0	20.1
	150.3	0.0	0.0	540.0	168.2	0.0	24.6	232.6	0.0	190.6
	141.7	53.9	135.0	0.0	255.0					

Table 8. (cont.)

358	0.0	695.9	0.0	0.0	0.0	410.2	0.0	0.0	0.0	356.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	292.6
	13.9	0.0	0.0	0.0	0.0	556.5	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	.2	330.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	661.2	0.0	3.0	0.0	540.0	0.0	.1	0.0	0.0	0.0
	196.3	12.0	349.2	0.0	0.0					
359	0.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0	0.0	0.0
	0.0	0.0	0.0	314.8	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	346.9	0.0	0.0	291.2	0.0	0.0	163.8
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	280.1	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	34.2	0.0	0.0	0.0	0.0
	0.0	614.4	0.0	0.0	0.0	540.0	0.0	0.0	288.5	0.0
	0.0	0.0	0.0	0.0	0.0					
360	0.0	0.0	0.0	0.0	0.0	335.2	0.0	0.0	0.0	309.3
	0.0	274.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	296.7
	316.0	0.0	0.0	0.0	0.0	409.9	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	273.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	540.0	0.0	0.0	0.0
	449.0	468.6	375.0	0.0	0.0					
361	297.7	207.1	43.2	133.9	0.0	187.8	0.0	0.0	0.0	181.1
	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	609.7	171.9
	14.7	2.4	0.0	0.0	0.0	197.9	0.0	15.7	24.8	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	245.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	224.1	0.0	0.0	0.0	228.1	0.0	0.0	540.0	0.0	438.9
	190.0	10.1	182.7	0.0	216.3					
362	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	168.6	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	172.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	128.7	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	540.0	0.0
	0.0	0.0	0.0	0.0	0.0					
364	422.3	249.5	135.4	160.5	0.0	204.5	0.0	0.0	0.0	195.0
	0.6	6.9	0.0	0.0	0.0	0.0	0.0	0.0	125.5	187.0
	12.2	6.1	0.0	0.0	0.0	240.4	0.0	8.6	19.3	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	.2	293.6	0.0	0.0	0.0	0.0	0.0	0.0	.0
	270.5	0.0	0.0	0.0	270.7	0.0	0.0	0.0	0.0	540.0
	220.7	6.8	198.5	0.0	0.0					
365	0.0	0.0	0.0	0.0	0.0	418.4	0.0	0.0	0.0	574.5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	488.5
	0.0	0.0	0.0	0.0	0.0	143.1	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	540.0	0.0	653.4	0.0	0.0					
366	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	417.4
	507.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	76.0	540.0	74.7	0.0	0.0					
367	0.0	0.0	0.0	0.0	0.0	136.8	0.0	0.0	0.0	199.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	678.4
	0.0	0.0	0.0	0.0	0.0	50.1	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	283.3	0.0	540.0	0.0	0.0					
368	158.6	141.7	141.9	144.1	172.0	126.6	171.3	0.0	303.3	120.4
	0.0	127.5	168.0	0.0	0.0	172.8	0.0	245.0	385.8	107.7
	102.9	143.0	0.0	0.0	0.0	131.8	0.0	147.9	154.8	0.0
	0.0	197.7	0.0	191.0	0.0	289.2	415.8	0.0	276.7	199.9
	4.9	120.0	151.5	0.0	0.0	0.0	0.0	0.0	0.0	135.5
	140.3	0.0	0.0	517.3	150.5	0.0	122.5	192.5	0.0	172.2
	124.9	103.0	117.0	540.0	199.9					
369	207.1	209.4	114.2	151.0	.4	186.9	7.9	0.0	0.0	160.2
	0.0	11.6	3.1	0.0	0.0	0.0	0.0	102.3	581.4	170.4
	29.1	20.4	0.0	0.0	0.0	197.1	0.0	24.5	45.7	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	.0	249.1	0.0	0.0	0.0	0.0	0.0	0.0	.5
	217.6	0.0	0.0	0.0	214.6	0.0	18.0	691.7	0.0	109.0
	188.5	16.1	188.7	0.0	540.0					

Source: Estimates by authors based on Vergeiner et al. (1981)